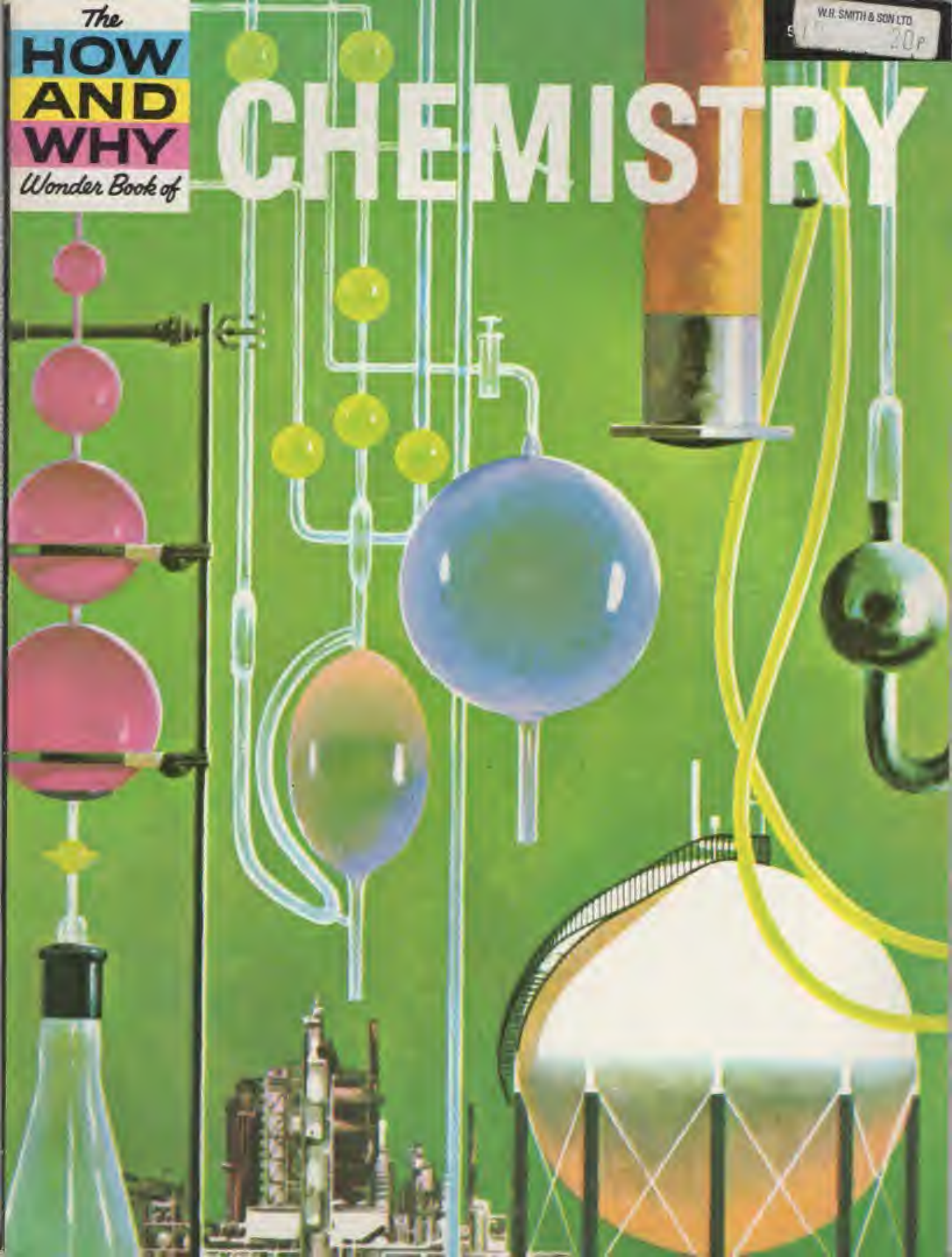


The
**HOW
AND
WHY**
Wonder Book of

W.H. SMITH & SON LTD
20p

CHEMISTRY





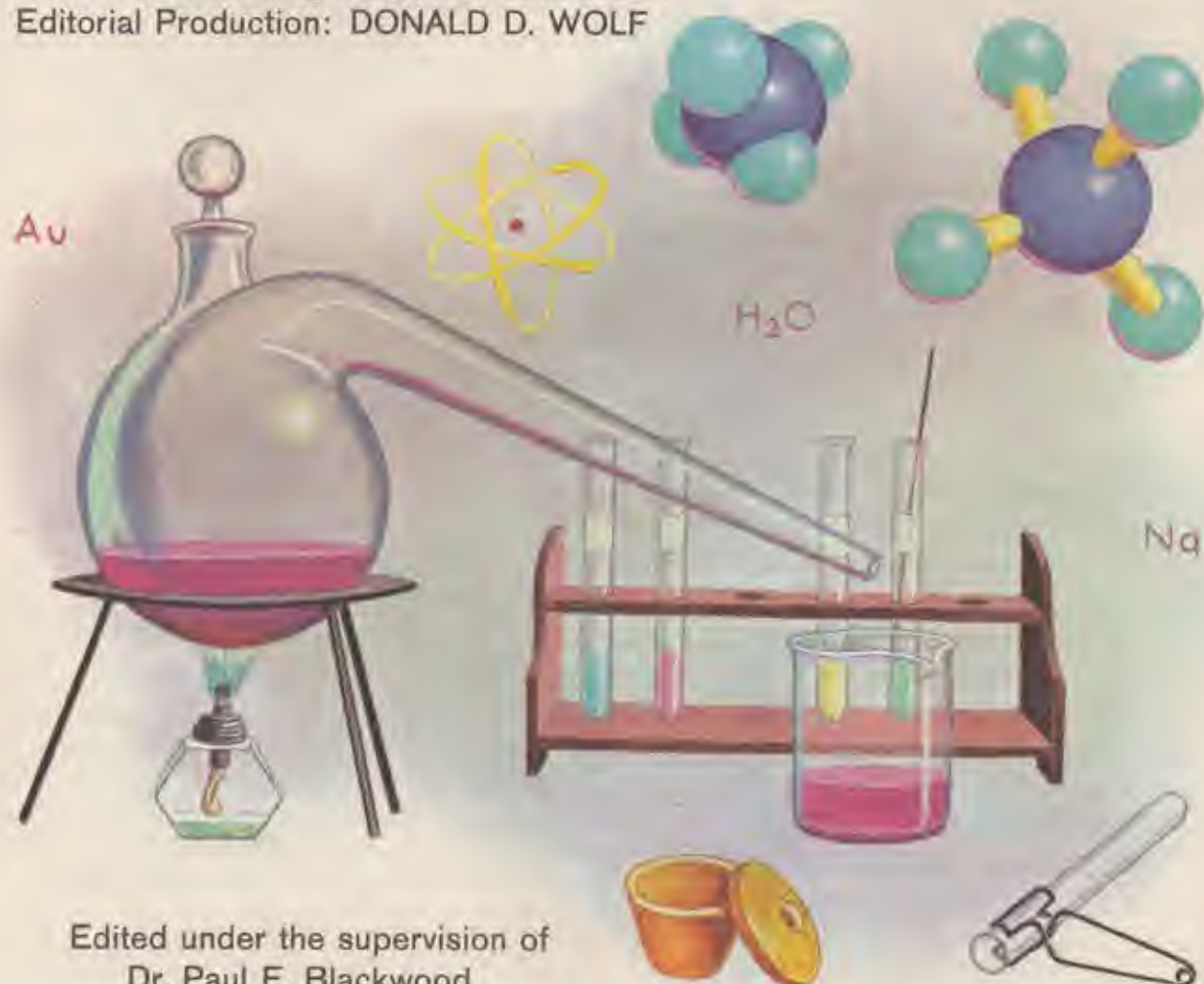
THE HOW AND WHY WONDER BOOK OF CHEMISTRY

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Introduction

What are things made of? This is the big question which *The How and Why Wonder Book of Chemistry* deals with. There are so many kinds of materials in our world that the question is not easily answered. But for centuries people have tried to find the answer. The search has been long and fascinating from the time of the alchemists down to the modern atomic scientist.

Once it was believed that all things were made of some combination of earth, air, fire and water. Little by little new discoveries were made. Now we know that instead of just four "building blocks," there are at least 103 different ones! This *How and Why Wonder Book* tells how scientists have made some of the discoveries along the historic path of chemistry. And it records the answers to many questions that have always puzzled people.

More than that, the reader gets a feeling of the unanswered puzzles of nature which challenge scientists to continue their explorations. How is it, for example, that carbon, a common element, appears in so many forms? Sometimes it is soot from the chimney; again it is graphite, the "lead" in an ordinary pencil; or perhaps, most surprising of all, it is sometimes the brilliant and lovely diamond! Equally astonishing is that a green gas and a silvery metal solid may combine to make a white solid — ordinary table salt!

Of special interest to many readers will be several chemical experiments in the book, which may be done at home or in school. The experiments will enable young scientists to rediscover some of the facts about matter while working with materials the way chemists do. Whether chemistry deals with metals or non-metals, with acids, bases and salts, with foods, drugs, plastics, or with living or non-living things, it always goes back to one basic thing: *matter*. Since this book deals with many of these subjects, it is really an introductory reference work for all young students interested in chemistry. It is an essential title in the growing list of *How and Why Wonder Books*.

Paul E. Blackwood

Dr. Blackwood is a professional employee in the U. S. Office of Education. This book was edited by him in his private capacity and no official support or endorsement by the Office of Education is intended or should be inferred.

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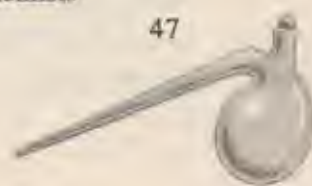
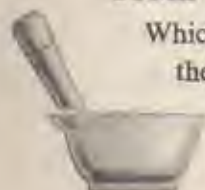
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Early man probably got his knowledge of fire from the world of nature around him. From his observations of erupting volcanoes, and fires caused by lightning and sunlight, man soon discovered that fire could be put to useful purposes. Thus, he might be considered the first chemist, and it is a fascinating journey from that day to the role of present-day chemistry.



What Is Chemistry?

It is impossible to look around your home without seeing some of the things chemistry had a part in making. It was chemists who learned how to make the plaster that covers the inside walls. Perhaps the walls are painted. Chemists directed the making of oils and colour in the paint.

Probably some of your clothes, the rugs, the curtains or the covering of your chair or sofa are woven of rayon, nylon or some other one of the man-made fibres that chemists have developed.

In the kitchen are foods that were bought in fresh condition because chemists made materials to preserve the foods

PRODUCTS
OF
MODERN
CHEMISTRY



from rotting. Chemists also made sprays that the food growers used to kill worms and other insects that might have eaten into the fruits and vegetables. Perhaps at this very moment some food is being cooked in your home. Cooking is a kind of chemistry.

In your bathroom are soaps and medicines that would have been impossible to produce if their makers did not have a knowledge of chemistry.

You probably have had toys made of plastic materials. Plastics would not even exist but for the science of chemistry.

If it were not for chemistry, the paper on which this book is printed would be a dirty, speckled brown, so that you could hardly read the words on it. And the ink in which these words are printed was made by chemists.

If you think about all these things in which chemistry had a part in making, you will see that none of them is found as such in nature. None can be grown on plants or trees, nor obtained from parts of animals, nor dug from the earth. Where, then, did they come from? Chemists took materials that *are* grown on plants and trees, obtained

from parts of animals, dug from the earth or taken from air or water; and the chemists changed these natural materials into other materials — the ones from which the things in your home are made. It is this *changing of one kind of material into another* that is the chief business of chemistry. For example, nylon is made from parts of coal, air and water, and some paints are made from parts of soya beans.

There is one other main task of chemistry: to describe carefully the many materials and their parts. A chemist who discovers or makes a certain material must describe that material carefully so that other chemists can recognize or make the new material themselves. How does a chemist describe materials? He tells what their colours are, whether they are light or heavy, shiny or dull, hard or soft. He is careful to tell whether the material is a solid, a liquid or a gas. He tells whether the material will sink or float in water, whether it will dissolve in water, in alcohol or in other liquids, how it will act when heated and many other things. These things are called the *properties* of the material.

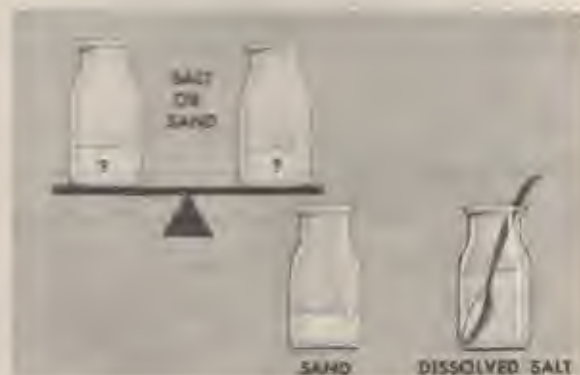
Let us see how this knowledge might be of use. Suppose you had two glass jars, one filled with salt and the other with clean white sand. Suppose you did not know which jar was filled with salt and which with sand. You would not want to put sand on your food, so you would have to find some way of telling what was in each jar.

As you looked at each jar you would see that its contents appear just about like that of the other jar. So, just look-



ing would be of no help. Suppose, then, you were to ask a chemist which is heavier — salt or sand. He would tell you that sand is heavier, but so little heavier that it wouldn't do much good to take one jar in one hand and the other jar in the other hand, and try to feel which is heavier.

The chemist would also be able to tell you that salt easily dissolves in water, while sand does not dissolve at all. Now, knowing this, all you have to do is to take a pinch of material from one of your jars, drop it into a glass of water, and stir. If the material dissolves, it is salt; if not, it is sand.



Salt will dissolve in water; sand will not dissolve.



Perfume was known in ancient Egypt. The picture, after a tomb painting, shows women preparing perfume.



The ancient Egyptians were casting bronze in 1500 B.C. The illustration, after a painting on the wall of an Egyptian tomb, shows workmen lifting a crucible to fill containers with the metal. In the background is a furnace, and on the floor, foot-operated bellows.

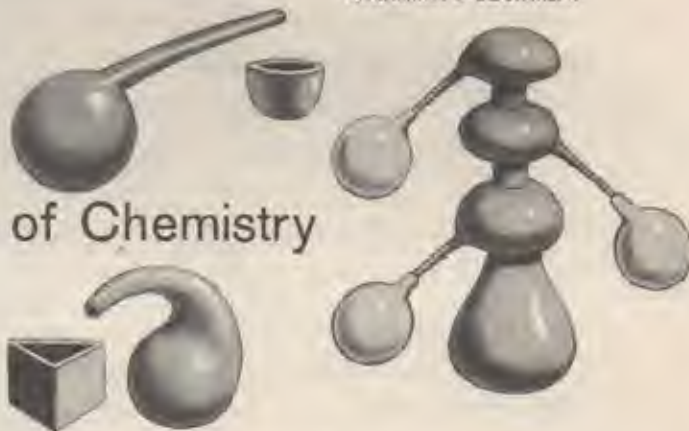
The Ancestors of Chemistry

Men were making use of chemistry long

How did chemistry begin?

before they knew anything about the science of chemistry. For example, the ancient Egyptians, more than 3,000 years ago, had learned skill in working iron. This metal is found in the earth combined with other materials to make a reddish brown rock-like material. In this form, it is called iron ore. For the Egyptians to separate the metal from the rest of the iron ore required a real use of chemistry. The Egyptians and several other ancient peoples who lived on the shores of the Mediterranean Sea mined silver, gold, lead, tin and copper. They knew how to combine copper and tin to form bronze, a metal that is quite hard, but from which it is easy to make things.

ALCHEMIST'S EQUIPMENT



Ancient peoples made spears, swords, helmets, bells, horns, chariots, chairs, pots, pans and a host of other things from bronze. To combine copper and tin in just the right amounts for making bronze was a skill that also required a use of chemistry.

The ancient Egyptians could make glass, tile, turpentine, soap and dyes. To make any of these things requires the use of chemistry. So good were the Egyptians at making them that some of their coloured glass and tile have been dug up from the earth where they were buried for thousands of years — and the colours are as bright as when

The alchemists, the forefathers of today's chemists, tried to make gold out of other metals, searched for a drink that would give eternal youth and everlasting life, and sought a liquid that would dissolve anything. Many alchemists worked seriously to achieve their goals. The walls of their laboratories were covered with secret symbols, and many pieces of laboratory equipment they developed are still in use.

the glass and tile decorated the palaces of Egyptian pharaohs. Egyptian pictures in coloured tile show ships with bright-coloured stripes dyed in their sails, and nobles, both men and women, wearing beautifully coloured clothes. All these facts are still more evidence that the Egyptians knew how to do things that required the use of chemistry.

The Romans knew how to make cement. They made such good cement that some of their roads and aqueducts, built of cement two thousand years ago, can still be used today. The hardening of cement is a chemical process. This shows that the Romans, too, knew how to make materials that required the use of chemistry.

Empedocles: all things are made of four elements



An ancient Greek wise man named Empedocles taught that all materials are made of four things called *elements*: earth, air, water and fire. For two thousand years after Empedocles, certain men tried to make different kinds of materials by combining these four elements in different ways. Fortunately, for the future of chemistry, these men thought of earth as including anything solid, such as ore, metal, salt, glass or wood. Also, they counted any kind of gas as air and any liquid as water.



Jugs of coloured water, symbolic colours originated by the alchemists, are still used today in modern pharmacies as a professional sign.

What these men were most interested in doing was to change cheap metals, such as tin, iron and lead, into gold. Where did they get the idea that less valuable metals could be turned into gold? The idea came from another ancient Greek, Aristotle, who had written that all things had the possibility of becoming perfect. Gold was considered to be the only perfect metal, and many people reasoned that less perfect metals could

How did chemistry get its name?

be changed into gold — if one could only learn how. And if one *could* learn how, men of olden times thought, what a wonderful way to become rich! The man who could learn the secret of changing a metal like lead into gold would soon be richer than anyone else. It was not hard to get hundreds of pounds of lead, but very few men owned even an ounce of gold.

The work of trying to change less valuable metals into gold was called *alchemy*, and the men who did this

work were *alchemists*. It was from these words that we got our modern words *chemistry* and *chemist*. Because of the work they were doing, alchemists were given the nickname of "gold cooks." In the courts of many kings and nobles, the gold cooks held an honoured place. One emperor built, near his palace, six small stone houses with large furnaces for the use of the royal alchemists. King Henry VI of England told his noblemen and scholars that alchemy was a valuable study that they should all learn.

Besides gold, there were two other things that alchemists tried to make in their laboratories. One was a liquid that would dissolve anything. They never stopped to think that such a liquid would also dissolve any bottle or other container in which they tried to keep it. The other thing they sought was a drink that would make old people young, and would cause all who drank it to live forever.

For hundreds of years alchemists worked in vain, never discovering any of the things they sought. They worked in smoke-blackened laboratories filled with the strange fumes and odours given off by the liquids they boiled and the powders they burned. The stone walls were covered with mysterious signs that were supposed to have magic powers. The red light of the fires in the alche-



mists' furnaces cast weird shadows and made eerie gleams dance on the odd-shaped glassware in which the gold cooks heated and stored their brews.

Alchemists found that a number of materials were especially useful in their work. Also, they discovered some new materials.

They wanted to keep their knowledge of these materials secret from all except other alchemists. To do this, alchemists devised a number of signs, or *symbols*, that stood for the names of the metals and other substances with which they worked.

Following are the signs that alchemists painted on the walls of their laboratories. Alchemists liked to believe that their symbols made alchemy seem mysteriously important to those who were not alchemists. In addition to the alchemical symbols are the materials the symbols stand for:

GOLD	SILVER	COPPER	IRON	TIN	LEAD	MERCURY	SULPHUR
NICKEL	ARSENIC	ANTIMONY	WATER	FIRE	SALT	CAMBRIC	URINE

AN ALCHEMIST'S CONCEPT FOR MAKING GOLD



Some alchemists were dishonest. They

**What happened
to alchemy?**

cleverly hid small
lumps of gold in
their furnaces.

Then, in the presence of those from whom they got money, the alchemists "discovered" the gold in the ashes of one of their experiments. And then, they claimed that if they were given more money for more experiments, surely a way would be found to get

really large lumps of gold out of the ashes.

Other alchemists were honest. In the hundreds of years of their fruitless experimenting, they gathered a long list of useful facts about their work. They described the ways in which many materials acted when mixed together or heated or shaken. They learned which liquids would dissolve metals and other materials, and which liquids would dissolve in others. They recorded the weights and colours and many other facts.

It is only about two hundred years since the last alchemist gave up his hopeless search. But the information gathered by him and the alchemists who lived earlier made up a store of knowledge, some of which became the basis for the true science of chemistry.

The Language of Chemistry

Every science has words that describe things and ideas with which the science deals. The words chemists use when they talk about their work are called "chemical terms," and they are important to know if we are to understand the science of chemistry.

MATTER

The first word is *matter*. When a chemist talks about matter, he means anything that has weight. Anything you can see or touch is matter. This book, your

**What is
matter?**

Anything that has
weight is matter.



nose, ice cream, a rock, water, milk, air, the sun, moon and stars are all examples of matter.

Are there any things that are not matter? Yes. Radio waves and television waves and heat are among the things that have no weight, and therefore are not matter. Also, ideas and feelings are things, but they are not matter. Patriotism, love, sadness, memories and daydreams have no weight and are not matter.



Water can be found in three states.

The objects in the world about us seem to be made up of an endless number of different kinds of matter. Things are made of

wood, paper, metal, rubber, cloth, plastic and a host of other materials. There is rough and smooth matter, hard and soft matter — and all matter appears in a great variety of colours and shapes. There are millions of different kinds of matter. Yet, a chemist separates all matter into three divisions: matter that is *solid*, matter that is *liquid* and matter that is *gas*. Each one of these large divisions of matter is called a *state of matter*. A rock and a golfball are examples of matter in the solid state. Water, milk and petrol represent matter in the liquid state. Air is matter in the state of a gas.

If you place an ice cube in a glass half full of water, you can see all-three states of matter at one time. The ice is solid, the water is liquid and the air above the water is gas.

Place two or three ice cubes into an empty teakettle. Put the kettle on a burner of a gas cooker. Keep the flame of the burner

low and leave the lid off the kettle. What happens inside the kettle? The ice melts; that is, it changes to water. Here, you see a solid changing to a liquid.

Put the lid on the kettle and turn the burner up higher. When the water in the kettle boils, look at the spout from the side. Between the spout and the steam, you will see a clear space. In this space is *water vapour*; that is, water in the form of a gas. (Do not try to touch the water vapour! It is very hot, and will give you a bad burn.)

The steam, which begins to appear just in front of the water vapour, is made up of tiny droplets of water. Upon leaving the spout, the water vapour came in contact with the cooler air, and the gas (water vapour) changed to a liquid (water). If you want to prove that cooling water vapour changes to water, wrap a towel around the handle of a table-spoon and hold the bowl of the spoon in the water vapour. (Be careful!) Drops of water will collect on the spoon.

If you should put the water that collects on the spoon into the freezing compartment of a refrigerator, the water would turn to ice. Thus, you would have an example of matter in the liquid state turning to matter in the solid state.

Most kinds of matter can exist in each

What are the three states of matter?

How can you change one state of matter into another state?

of the three states. Iron can be melted and, thereby, changed from the solid to the liquid state. The iron becomes liquid when it is heated to 2,800 degrees Fahrenheit. (The usual temperature inside a house is about 70 degrees Fahrenheit.) If liquid iron is heated further, until its temperature reaches 5,400 degrees Fahrenheit, the iron boils and becomes a gas.

You have probably noticed the bubbles in soda. These bubbles are made of *carbon dioxide*, a harmless gas. If you were to put some of this gas into the proper kind of container, and then lower the temperature to 69 degrees below zero Fahrenheit, the carbon dioxide gas would turn to liquid carbon dioxide. If you cooled the liquid carbon dioxide further, until its temperature dropped to 110 degrees below zero Fahrenheit, the liquid would become solid. Perhaps you have seen solid carbon dioxide. It is called "dry ice," and is used by street vendors of ice cream to keep their wares cold.

You have probably guessed that by changing the temperature of matter, you can change it from one state to another. This is true. Heating and cooling matter are the main ways chemists use to change it from one state to another.

Tanning animal hides makes them into leather by causing a chemical change that prevents rotting. After soaking hides in salt water to remove dirt and blood, ancient tanners rubbed the hides with lime to remove the hair. The limed hides were washed and hung on sticks in vats of tanning solution made by soaking bark, leaves, wood or nuts in water. The leather was rubbed with oil to make it soft. This process has been replaced by new methods (right).



REMOVING HAIR
IN WASHING DRUM
FILLED WITH LIME



SCRAPING FLESH FROM
THE INSIDE OF HIDE



SPRAYING WITH BETA NAPHTOL TO DESTROY HIDE-ATTACKING BACTERIA



CHEMICAL ELEMENTS

We have learned that the ancient Greek,

What is a chemical element?

Empedocles, said the elements of which all things are made are earth, air, water and fire.

Now an element of anything is a part so simple that it cannot be divided into any simpler parts. When alchemists worked with various solid materials that they believed to be forms of the element *earth*, they soon learned that many of these solid materials could be separated into simpler materials. This proved that *earth* was not really an element. On the other hand, alchemists found that certain materials — almost all of them metals — could not be separated into simpler parts. These indivisible materials were true *chemical elements*. The elements the alchemists knew were gold, silver, copper, iron, lead, tin, mercury, antimony, sulphur, arsenic, phosphorus and carbon. You have probably recognized that many of these are names of metals known to the ancient Egyptians, who also knew of sulphur and carbon.

Mercury was probably discovered about the year A.D. 300 by a Greek named Theophrastus, while the elements arsenic and antimony were discovered in the Middle Ages.

In the eighteenth century, when chemistry was becoming a science, chemists began to discover new chemical elements. The discovery of elements went on until chemists had found 92 elements in materials obtained from the earth and the air. Then, recently, chemists learned how to make new chemical elements, and have made eleven more for a total of 103 elements. On page 15 of this book you will find a list of all the chemical elements discovered up to the time these words were written.

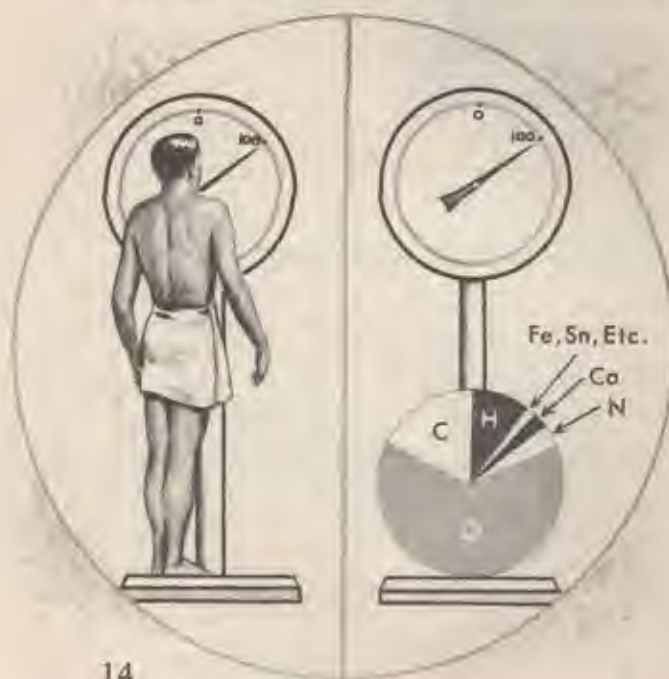
It is an important fact that chemical elements are the simplest kinds of matter with which a chemist works.

CHEMICAL SYMBOLS

Following the name of each element in the list on page 15, you will see one or two letters. For instance, following *calcium* are the letters *Ca*.

What are chemical symbols?

These letters are an abbreviation of the name of the element. Chemists find that using these abbreviations is easier



if you weigh 100 pounds, your body is made up of roughly 65 pounds of oxygen, 18 pounds of carbon, 10 pounds of hydrogen, 3 pounds of nitrogen, 2 pounds of calcium, 1 pound of phosphorus. The remaining pound consists of iron, zinc, potassium, sodium, chlorine, fluorine, bromine, iodine, magnesium, manganese, copper, chromium, molybdenum, titanium, rubidium, strontium, sulphur, selenium, boron, nickel, arsenic, cobalt, silicon, lithium, aluminium, tin, and barium. Altogether, your body has 33 elements.

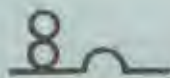
TABLE OF CHEMICAL ELEMENTS

Actinium	Ac	Erbium	Er	Mercury	Hg	Samarium	Sm
Aluminium	Al	Europium	Eu	Molybdenum	Mo	Scandium	Sc
Americium	Am	Fermium	Fm	Neodymium	Nd	Selenium	Se
Antimony	Sb	Fluorine	F	Neon	Ne	Silicon	Si
Argon	Ar	Francium	Fr	Neptunium	Np	Silver	Ag
Arsenic	As	Gadolinium	Gd	Nickel	Ni	Sodium	Na
Astatine	At	Gallium	Ga	Niobium	Nb	Strontium	Sr
Barium	Ba	Germanium	Ge	Nitrogen	N	Sulphur	S
Berkelium	Bk	Gold	Au	Nobelium	No	Tantalum	Ta
Beryllium	Be	Hafnium	Hf	Osmium	Os	Technetium	Tc
Bismuth	Bi	Helium	He	Oxygen	O	Tellurium	Te
Boron	B	Holmium	Ho	Palladium	Pd	Terbium	Tb
Bromine	Br	Hydrogen	H	Phosphorus	P	Thallium	Tl
Cadmium	Cd	Indium	In	Platinum	Pt	Thorium	Th
Caesium	Cs	Iodine	I	Plutonium	Pu	Thulium	Tm
Calcium	Ca	Iridium	Ir	Polonium	Po	Tin	Sn
Californium	Cf	Iron	Fe	Potassium	K	Titanium	Ti
Carbon	C	Krypton	Kr	Praseodymium	Pr	Tungsten	W
Cerium	Ce	Lanthanum	La	Promethium	Pm	Uranium	U
Chlorine	Cl	Lawrencium	Lr	Protactinium	Pa	Vanadium	V
Chromium	Cr	Lead	Pb	Radium	Ra	Xenon	Xe
Cobalt	Co	Lithium	Li	Radon	Rn	Ytterbium	Yb
Copper	Cu	Lutetium	Lu	Rhenium	Re	Yttrium	Y
Curium	Cm	Magnesium	Mg	Rhodium	Rh	Zinc	Zn
Dysprosium	Dy	Manganese	Mn	Rubidium	Rb	Zirconium	Zr
Einsteinium	E	Mendelevium	Md	Ruthenium	Ru		

than writing out the whole name of the element. Chemists call the abbreviations *chemical symbols*. This name is inherited from alchemists who, as we learned, actually used symbols to refer to chemical elements.

Some abbreviations are simply the first letter, or first two letters, of the element's name; for example, *iodine* (I) or *nickel* (Ni). Other abbreviations are composed of the first letter and one other letter in the element's name; for

example, *chlorine* (Cl) or *platinum* (Pt). These are easy to understand, but you may have noticed some abbreviations that are not made up of the letters in the element's name; for example, *gold* (Au). Why is this so? Because the letters of these abbreviations come from the Latin names of the elements. There is one other element whose abbreviation may puzzle you. It is *tungsten*, whose abbreviation is *W*. This is so because the proper name of



tungsten is *wolfram*, but it is a matter of custom in English-speaking countries to call this element tungsten. Here is a list of those elements whose abbreviations are derived from the Latin name:

ENGLISH NAME	LATIN NAME	ABBREVIATION
gold	aurum	Au
silver	argentum	Ag
copper	cuprum	Cu
iron	ferrum	Fe
lead	plumbum	Pb
tin	stannum	Sn
mercury	hydrargyrum	Hg
antimony	stibium	Sb
potassium	kalium	K
sodium	natrium	Na



CHEMICAL COMPOUNDS

There are only 103 chemical elements,

What are chemical compounds?

but we know of almost a million other materials. What are these materials? They are

combinations of two or more chemical elements and are called *chemical compounds*. To *compound* means "to put together." Chemical compounds are made by putting together chemical elements.

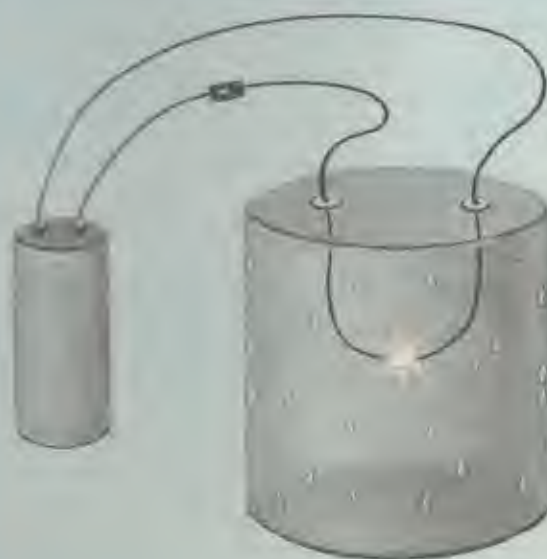
There are many compounds familiar to you. Water is one. Salt is another. Vinegar, sugar, aspirin, chalk, epsom salts, petrol, lime, marble, rouge, washing soda and alcohol are still other compounds you know. Most of the materials you handle or use are chemical compounds or mixtures of chemical compounds.

Let us see of what elements a few familiar chemical compounds are made. (As you read the following, you may

want to refer to the table of chemical elements.) Water is made of the elements *hydrogen* and *oxygen*. Table salt is made of *sodium* and *chlorine*. Chalk is made up of *calcium*, *carbon* and *oxygen*. Rouge is a combination of *iron* and *oxygen*. Alcohol is composed of *carbon*, *hydrogen* and *oxygen*.

When we say that water is made up of the elements hydrogen and oxygen, do we mean that if we mix together some hydrogen and some oxygen, we will have some water? No, for in order to make a chemical compound, we usually must use very special means of combining chemical elements. For example, if we were to put some oxygen in a jar that we previously emptied of air, and then were to add twice as great a volume of hydrogen, we would not be able to tell the contents of the jar from air simply by looking. But if we put into the jar two wires connected to an electric battery, and made a spark jump between the ends of the wires, we would cause an explosion within the jar. And

Water is a compound of oxygen and hydrogen.



all around the sides of the jar would appear tiny drops of water. Since there was nothing at all in the jar until we put the hydrogen and oxygen into it, the water must have come from the combination of the two elements put into the jar. A chemist says that the hydrogen and oxygen *combined chemically* to form the compound called water.

An electric spark is not the only method of causing elements to combine into compounds; in fact, it is a rare method. One very common method is to heat the materials that we want to combine into compounds. Another method is to dissolve materials in water or other liquids, and then to mix the liquids, perhaps also heating them.

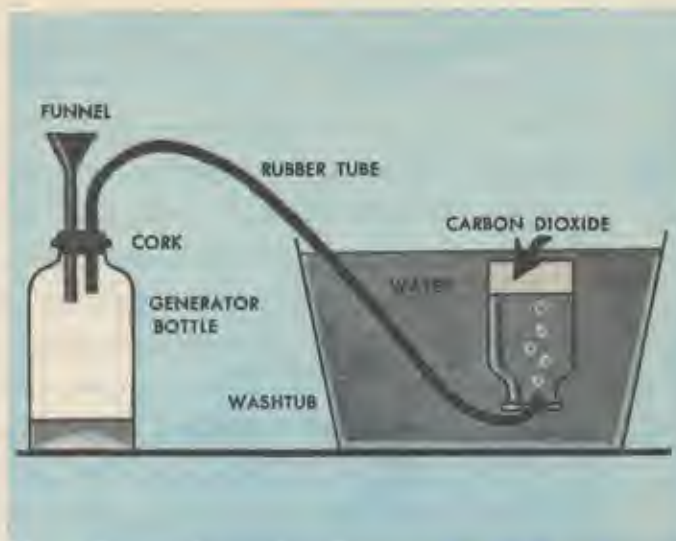
Since all compounds are made of elements, and since elements can be combined in so many different ways to make so many thousands of compounds, you can probably see the similarity between chemical elements and building blocks. It is because almost all the materials that we know of in the universe are made up of elements, compounds, or mixtures of these two, that elements are truly the building blocks of the universe.

Fill a tumbler half full of vinegar.

**How can you
make a compound?**

Crush a small
piece of chalk.
(If some kinds

of chalk don't work, use crushed egg shell.) Drop the chalk into the vinegar. Soon you will see bubbles rising from the chalk. Where did they come from? They are made of *carbon dioxide* gas. This gas is composed of the elements carbon and oxygen combined into a single compound — the carbon dioxide.



To make carbon dioxide, set up this apparatus. Place one-half inch of bicarbonate of soda in the generator bottle. Pour three ounces of vinegar into the funnel. To put the collection bottle in place, fill it with water, place your hand tightly over its mouth, turn it upside down under water, remove your hand.

The carbon and the oxygen, along with the element calcium, made up the chalk. The vinegar was able to remove the calcium from the chalk compound, leaving the carbon and oxygen to form the gas.

To combine two or three or more ele-

**In what other
ways can we
make compounds?**

ments in order
to make com-
pounds is an
unusual way of

doing things in chemistry. Pure elements are difficult to obtain and are therefore expensive. Also, certain elements seem to be so eager to combine with others that it is difficult to keep them pure until we want to use them. Other elements seem so unwilling to combine that they require a great amount of trouble and expense to cause them to join with others. (Of course, chemical elements have no feelings, so they cannot really be "eager" or "unwilling," but to think

of them in this way helps us to understand their actions.)

By far the most common way of making chemical compounds is to bring together two or more compounds and exchange elements between them. For example, suppose we want to make some table salt. We learned that table salt is made up of the elements sodium and chlorine. We could make salt by simply bringing together some sodium and some chlorine. But if we actually tried this, we would find that we had problems on our hands. Chlorine is a very poisonous green gas, so it is difficult and dangerous to handle. Sodium is a metal that combines very easily with the oxygen of the air so that we would have a hard time to keep it pure until we could bring it into contact with the chlorine. And then, even if we solved these problems, there would be another,

for when the chlorine and sodium were brought into contact, they would begin to combine so energetically that an explosion would result.

There is, however, a very neat way in which we can combine sodium and chlorine. We could obtain two inexpensive, easy-to-handle powdered compounds called calcium chloride and sodium carbonate. Calcium chloride is made up of the elements calcium and chlorine, and sodium carbonate is made up of the elements sodium, carbon and oxygen. Now, both these compounds can be dissolved in water without combining with the water. Having dissolved the calcium chloride and the sodium carbonate in separate containers of water, we pour the water from both containers together. What happens? Again speaking figuratively, the sodium rushes into the arms of the chlorine, and the



CALCIUM
CHLORIDE



SODIUM
CARBONATE

DISSOLVE EACH
IN SEPARATE
CONTAINERS



COMBINE LIQUIDS
FROM BOTH
CONTAINERS



By combining two elements, sodium, a pliable metal and chlorine, a poisonous gas, we get a harmless compound, sodium chloride.

DISSOLVED TABLE SALT
PLUS UNDISSOLVED CHALK



WEIGHT OF SALT
BEFORE AND AFTER
DISSOLVING CHALK

calcium joins hands with the carbon and oxygen.

The sodium and chlorine have formed table salt, but what have the rest of the elements made? The leftover elements are calcium, carbon and oxygen. You may remember we learned that chalk is made up of calcium, carbon and oxygen — and chalk is exactly what the rest of our elements have combined to make. This chalk is in the form of very, very fine particles.

Chalk will not dissolve in water. So, the tiny particles of chalk simply settle to the bottom of the container of water. Let us wait for all the chalk to settle. Then we very carefully pour the water (and the salt dissolved in it) into a pan, leaving the chalk behind. We heat the pan until all the water boils away, and left on the bottom of the pan is pure *sodium chloride*, or table salt.

ATOMS AND MOLECULES

All matter is made up of extremely

What are atoms and molecules? small particles called *atoms*.

Atoms are so small that no microscope, no matter how powerful, can enable you to see them. One hundred million atoms, side by side, would make a row only one inch long. We know of 103 kinds of atoms, each of a different size. Does the number 103 remind you of anything? You probably remember that there are 103 chemical elements. Each element is made up of just one kind of atom. We

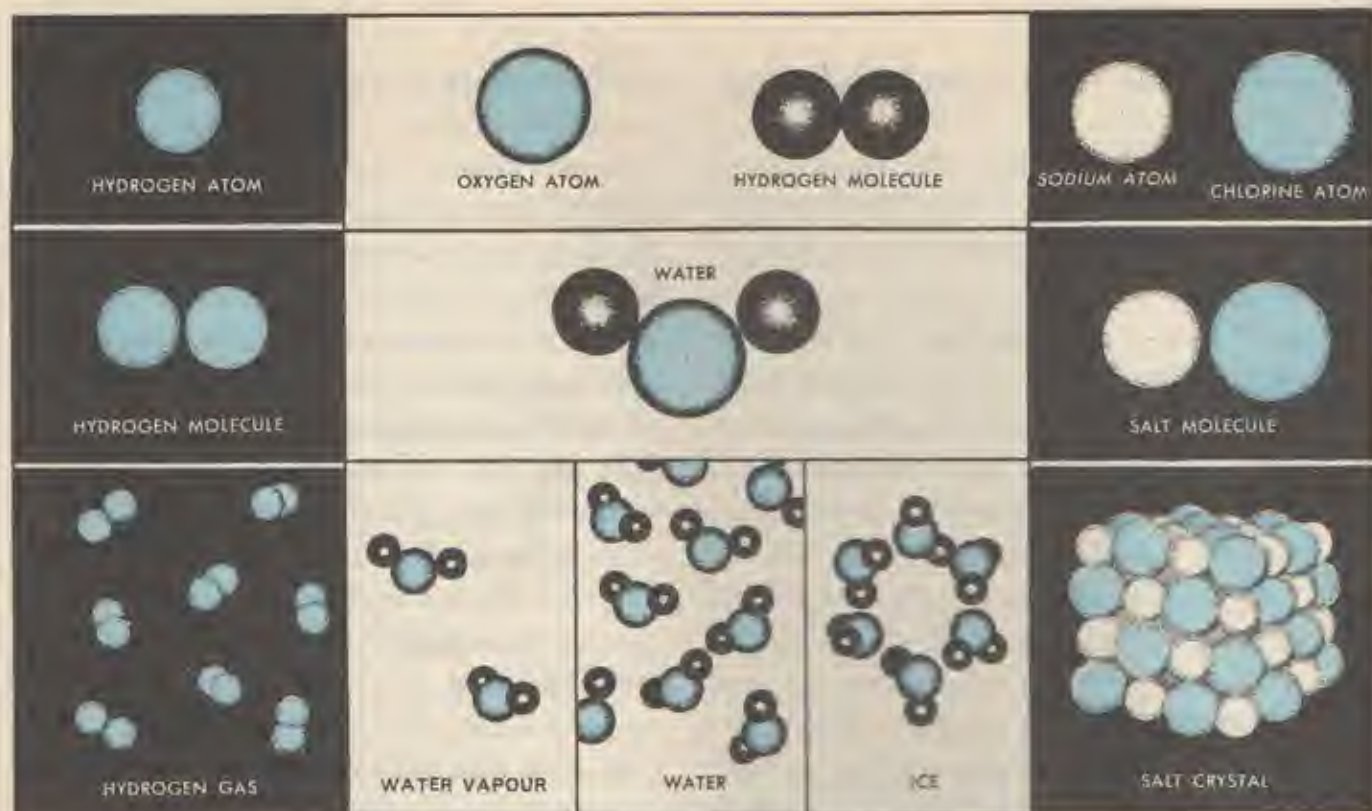
learned that an element is matter that cannot be divided into simpler parts. Now we can see that this is true because all of an element is made up of atoms of the same kind. No matter how much we divide up an element, we still have the same kind of atoms. (Of course, you may have heard of scientists who split, or smash, atoms. But when an atom is split, part of it becomes heat and light — and we learned that heat and light are not kinds of matter. So, we cannot properly say that splitting an atom divides it into simpler parts.)

We learned that elements are the simplest kinds of matter with which a chemist works. Now that we know what an atom is, we can add that an atom is the smallest unit of matter with which a chemist works.

Atoms sometimes exist by themselves, without connection to other atoms. Mostly, though, atoms form groups with other atoms. There may be only two atoms in a group or there may be hundreds. These groups of atoms are called *molecules*.

Sometimes two atoms of the same element join together to form a molecule. Chemists tell us that this two-atom molecule makes up most gases — hydrogen, oxygen and nitrogen, for example.

Usually, a molecule is made up of atoms of different elements. We learned that a chemical compound, too, is made up of different elements. Now, we can add that a compound is made up of molecules. When we learned that elements combine to make compounds, what we also meant was that atoms combine to make molecules.



Two hydrogen atoms combine to form a hydrogen molecule. Hydrogen gas is made of hydrogen molecules.

When two hydrogen atoms join an oxygen atom, a water molecule is formed. In water vapour, there is much room between the water molecules. In liquid water, they are closer together. In ice, they form shapely ice crystals.

When a sodium atom joins a chlorine atom, they form a sodium chloride molecule. These molecules join to form salt.

You probably know that a magnet will attract a piece of iron or steel, and that two magnets will attract each other. Atoms act like tiny magnets. They attract each other and join together. Since there are 103 different kinds of atoms, there are a vast number of ways in which they can join together. This is why there are so many compounds.

Not only can atoms join in so many different combinations, but also in many different patterns. Let us see some of these patterns. Suppose you could enlarge atoms until they became as large as marbles. With these large atoms, you could make models of molecules.

You might place two atoms side by side to form a model of a gas molecule.

You might add a third atom so as to form a *triangular molecule*. This would be the model of a water molecule. The oxygen atom would be larger than the two hydrogen atoms joined to it. If you wanted to add a fourth atom, you would place it on top of the other three, so as to form a little pyramid. In this case, the atoms would all have to be nearly the same size.

You might join all your atoms in a single row. Certain atoms actually do join in long rows, or chains, as the chemist calls them. You might join your atoms in the form of a circle. There really are molecules that are in the form of circles, or rings, as the chemist calls them. We shall learn more about chains and rings, because these arrangements of atoms make molecules of the greatest importance to man.

MIXTURES

We have been talking about mixtures of many kinds of materials. In chemistry, we must clearly understand

**What is
a mixture?**

what a mixture is, so let us make one. We take a handful of the element *iron* in the form of filings; that is, in the form of powdered iron. Then we take a handful of the element *sulphur*, also in the form of a fine powder. We put enough of the two handfuls into a bottle so that the bottle is only half full. We cap the bottle and roll it around and around. Doing this thoroughly mixes the particles of iron and sulphur.

Is the mixture the same as a compound made up of iron and sulphur? No, because there are two important differences. To understand what these differences are, let us try two experiments.

First, let us see whether we can think of a way to separate the particles of iron and sulphur that make up our mix-

Sulphur and iron joined in a mixture stay unchanged.



ture. We might get a very fine pair of tweezers and try to pick all the particles of iron out of the mixture, thus leaving the sulphur behind. The trouble with this idea is that we couldn't get a pair of tweezers fine enough, nor probably have enough patience to pick out every single piece of iron. There is, however, an easy way to separate the iron and sulphur. We simply pull a magnet back and forth through our mixture. The iron particles cling to the magnet — the sulphur particles do not. Thus, we can separate the iron and sulphur, and no longer have a mixture.



Sulphur and iron joined in a compound do change.

Can we separate a compound of iron and sulphur in the same way? Let us see. We make the iron and sulphur mixture again. Now we put the mixture into a small porcelain crucible, or a test tube. We then heat the tube. At the proper temperature, the mixture begins to glow and give off heat, as if it were burning. When the glowing stops and the tube cools, let us dump out the contents and examine it closely.

Out of the tube comes a lump made up of black crystals. We no longer see particles of either iron or sulphur. If we bring a magnet close to the lump, nothing clings to the magnet. What happened to the particles of iron and sulphur that went into the mixture? They combined chemically to form the crystals that are a compound called *iron sulphide*. Can we separate iron sulphide into iron and sulphur? Yes, but doing so will be a long and complicated process in which we use many compounds and several chemical operations.

Now we can see what is the first difference

How do mixtures and compounds differ? **ence between a mixture and a compound:**

The materials that make up a mixture remain unchanged in the mixture; but the materials that go into making a compound change completely as they form the compound. We learned about a very dramatic change of this kind when we saw how two gases, hydrogen and oxygen, combine to form a liquid, water. There are thousands of solid compounds, part of whose ingredients are gases or liquids, and there are liquid compounds whose ingredients are solids or gases.

When we were making the mixture of iron filings and sulphur powder, we could have mixed together as much or as little of each of these ingredients as we wished. We could have used half iron and half sulphur or ten times as much of one as the other.

In making a compound we do not have a free choice of how much of each ingredient we will have in the com-

pound. In iron sulphide there is combined just one part of iron with one part of sulphur—no more and no less. If we had used more iron than sulphur, the extra iron would have been left over. (We may not have been able to see the extra iron just by looking, but if we had ground up the lump of iron sulphide and then pulled a magnet through the powder, we could have removed the *extra* iron, but not the iron that combined with the sulphur to make iron sulphide.)

Now we know the second difference between a mixture and a compound: A mixture can be made up of ingredients in any amounts, but a compound is made up of ingredients in only certain fixed amounts that are always the same.



There is one kind of mixture that does not act like other mixtures. Let us make it. First we take a glass of water into which we place a teaspoon of table salt. Stir the water with a spoon. What happens to the salt? It disappears. A chemist says that the salt *dissolves*. The water and the dissolved salt together make up a solution.

Let us pour the solution from the glass into a pan and put the pan on a lighted stove. We let the solution boil until all of the water goes up in steam. On the bottom of the pan is the same amount of salt as we dissolved in the glassful of water.

Insofar as the solution can be made up of ingredients in varying amounts, it is like a mixture. Also, the ease with which we separated the ingredients shows that they were not chemically combined to form a compound. In this way, too, a solution is like a mixture. But when the salt was dissolved in the water, we could not see separate parts of salt and water, for the salt had taken on an entirely new form. In this way the solution is different from a mixture.

There is more than one kind of solution. Not only can solids (like salt) be dissolved in liquids (like water), but liquids can be dissolved in other liquids, and gases can be dissolved in liquids. We have learned that the bubbles in soda water are carbon dioxide gas. We see bubbles only when the carbon dioxide begins to separate from the water in which it was dissolved.

Solutions are very important in chemistry. By dissolving materials — compounds and elements — in liquids, the chemist has his chief way of bringing materials together to form new



How do the chemists form new compounds? By dissolving materials — compounds and elements — in liquids, the chemist has his chief way of bringing materials together to form new

Nature is continually manufacturing fresh and salt water. The sun's heat evaporates water from the sea to form clouds that are made up of fresh-water droplets. Rain from the clouds runs through the ground and dissolves salt compounds. Streams and rivers carry the dissolved salts to the sea where the salt collects, and the sea becomes saltier. The sun evaporates more sea water as the process continues.

compounds. Do you remember that when we were learning about compounds, we found how to make table salt (sodium chloride) from two other compounds called calcium chloride and sodium carbonate? These latter two were powdered. If we simply mixed the powders together, kept them dry and left them alone, nothing would have happened. But we dissolved the powders in water. Then the compounds easily acted to form new compounds. In the chemical industry, dissolving compounds in liquids is probably the main way of bringing materials together to make new materials.

Solutions are important to us when we eat. Our tongues have certain areas in which there are small organs called *taste buds*. Different taste buds give us different taste sensations. There are taste buds for sweet, sour, salty and bitter tastes. We do not know exactly how taste buds work, but we do know that tasting is some kind of chemical

**How do we
taste things?**



Shown are the location of taste buds on the tongue.

action. How do we know this? Because we can taste only those materials that dissolve in liquids. Saliva is one liquid that dissolves some of our food materials; water is another.

If you want to prove that a material must be dissolved in order to be tasted, try to taste a clean spoon or the edge of a clean plate. Neither silver nor china can dissolve in your saliva. That is why you cannot taste either of them. Put a dry cracker biscuit in your mouth. At first, you will taste nothing. In a few seconds, your saliva will begin to dissolve the cracker, and you will taste it.

Some Interesting Elements

Each of the 103 chemical elements has an interesting story. Elements have different colours. Some are metals, some are crystals, some are liquids and some are gases. Elements are obtained in many different ways, and elements have many interesting uses. Let us look closely at a few of them.

We have learned that alchemists discovered several chemical elements, but we know about the actual discovery of only one of these elements. In 1669, a German alchemist, Hennig Brand,

**Which element is
noted for glowing
in the dark, and
how was it found?**

was trying to make gold from cheaper materials. Because gold was considered to be the most perfect metal, alchemists called it a "noble" metal. Brand reasoned that nothing could be more noble than the human body and materials connected with it. So, perhaps, it would be possible to change something connected with the noble human body into the noble metal, gold.

With this idea in mind, Brand mixed together some human urine and sand, and heated them in an oven. We do not know why he chose sand, but it was not unusual for alchemists to heat together any odd combination of materials that came to mind. When taken from the cooled oven, Brand's mixture glowed strongly in the dark. Brand had not, of

course, made gold, but he had made a soft, whitish, waxy material. This material had been in a compound dissolved in the urine, although Brand did not know this. He named the glowing material *phosphorus*, which is Greek for the words "I bear light." Phosphorus turned out to be an element — it could not be divided into simpler materials.

A century and a half after the discovery of this element, it was found that phosphorus mixed with other materials would catch fire when rubbed. This mixture was used to make tips for matches. Unfortunately, since phosphorus is very poisonous, many people who worked in match factories died from breathing the vapour of heated phosphorus. But fortunately, in 1845, another kind of phosphorus—red phosphorus—was discovered. It is not poisonous and eventually, all countries passed laws that



At the left is an alchemist's oven; right, Brand discovers phosphorus.





The English scientist Robert Boyle, in 1660, put a live mouse and a lighted candle into a sealed glass jar that was attached to a pump. He pumped the air out of the jar, and the candle went out and the mouse died. This proved to Boyle that he was right in believing that air contains a substance necessary to sustain life.



banned the use of white phosphorus in the manufacture of matches.

Phosphorus is very important to the

Why is phosphorus useful to humans?

proper growth of the human body, especially for the

development of healthy bones and teeth. Phosphorus is also needed to keep nerves and muscles healthy. The phosphorus in our bodies is combined with other chemical elements and is not at all poisonous. We can get enough phosphorus for good health from a balanced diet, especially from milk. Plants, too, need phosphorus, and this element is a part of most fertilizers.

Sometimes chemists need large amounts of phosphorus. To get it, they put burned bones or a certain kind of

rock, called phosphate rock, into a furnace along with sand and coke. In both the bones and rock there are compounds containing much phosphorus. This mixture is heated, and large amounts of phosphorus are obtained as a result of this process.

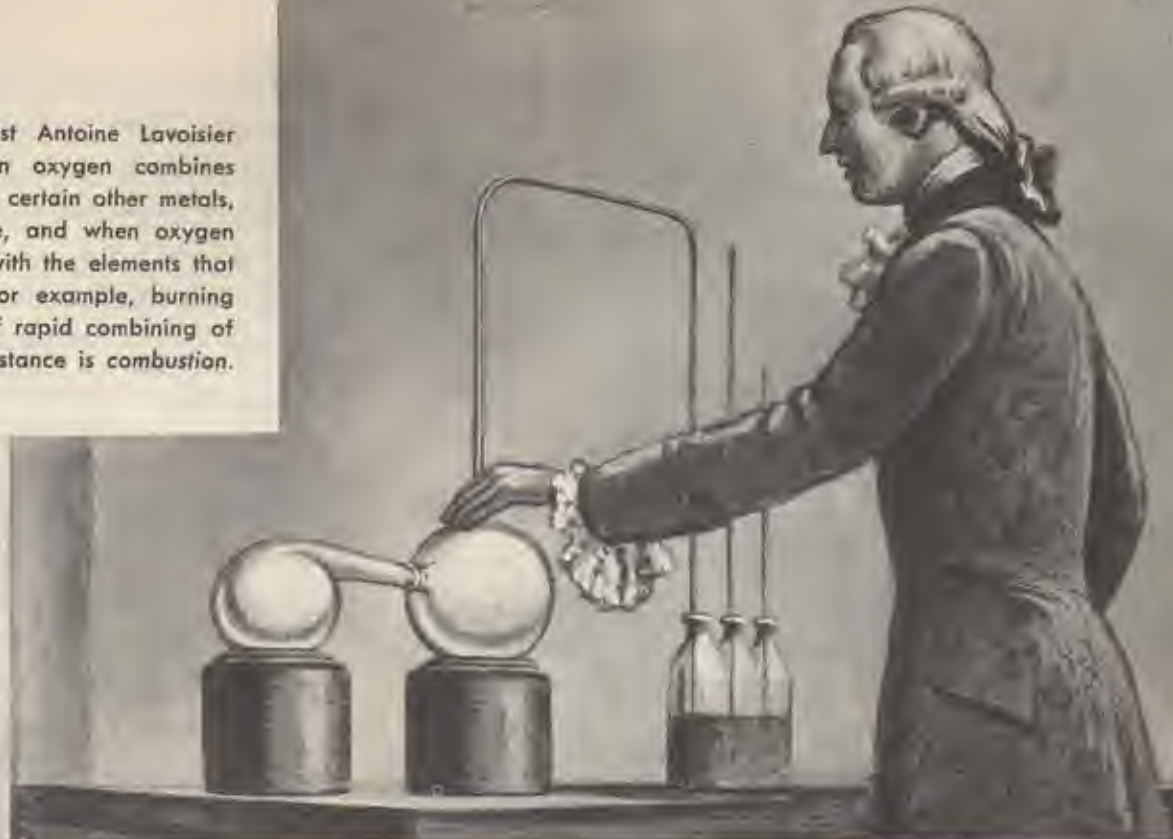
The most abundant element on earth is

What is the most abundant element in the earth's crust?

a colourless, odourless, tasteless gas that is important to you every moment of your life. This element is *oxygen*. One-fifth of the weight

element is *oxygen*. One-fifth of the weight

The French chemist Antoine Lavoisier showed that when oxygen combines slowly with iron or certain other metals, rusting takes place, and when oxygen combines rapidly with the elements that make up wood, for example, burning occurs. This sort of rapid combining of oxygen with a substance is combustion.



In the year 1771 Joseph Priestley, the English scientist, prepared oxygen by concentrating the sun's rays through a lens on mercuric oxide.

of the atmosphere and nine-tenths of the weight of all the earth's water is oxygen. Nearly half of the weight of the earth's rocky crust and one-third of the weight of the deeper rocks is oxygen. And oxygen makes up two-thirds of your body and the tissues of most other living things.

In the late fifteenth century, the Italian scientist and artist Leonardo da Vinci wrote that the atmosphere contained two different gases. Two hundred years later, an Englishman, John Mayow, discovered that one of the gases in air caused iron to rust and was

important to breathing. Sixty years later another Englishman, Stephen Hales, actually obtained some oxygen by heating a compound called saltpetre. Hales, like the alchemists, called all gases "air," and so he never knew he discovered a new gas. Exactly forty years later, a Swedish apothecary, Karl Wilhelm Scheele, produced some pure oxygen. He realized that he had discovered a new gas, but he did not have any way of telling the scientific world about it. Three years later, Joseph Priestley, an English clergyman, also produced pure oxygen. He immediately told his fellow scientists about his accomplishment. Scheele did not publish his results until three years after Priestley reported his discovery. For this reason, Priestley was for a long time given credit as the discoverer of oxygen, but now we say that both men deserve equal credit as the discoverers of this important element.

Oxygen is very useful in a chemical laboratory and also in industry. If we want just a little oxygen we

How can we get oxygen?

have several ways of obtaining it. We might get oxygen the way Priestley did; that is, we could heat a compound called mercuric oxide. This compound is a reddish powder that is composed of the elements mercury and oxygen. Gently heating mercuric oxide will cause the oxygen to separate from the mercury. There are a few other compounds from which we could get oxygen by heating them.

Still another way to get small amounts of oxygen is to run an electric current through water. We learned that water is composed of hydrogen and oxygen. The electric current separates the atoms of the water molecule, and water changes into hydrogen and oxygen.

In industry, much larger amounts of oxygen are needed than can be conveniently obtained by the methods described above. To obtain large amounts of oxygen, we turn to the air, which is one-fifth oxygen. This portion of oxygen is not combined with any other element. To separate the oxygen from the eight other gases that normally make up the atmosphere, air is put into containers under very great pressure. As a result the air becomes liquid and very cold. Then the pressure is gradually released and the liquid air is allowed to slowly warm up. As the warming takes place, each of the gases that make up the air boils off at a different temperature. Oxygen boils off at 297 degrees below zero Fahrenheit. As the oxygen boils off it is caught in other containers, and then

is stored in stout steel cylinders at a pressure of 2,000 pounds per square inch. The cylinders are shipped to laboratories or factories that use oxygen.

Did you ever think that there is a connection between a burning match and a rusting nail? Well, there is. When a

How is oxygen used by the human body?

match burns, oxygen is *rapidly* combining with some of the elements that make up the wood of the match. When a nail rusts, oxygen is *slowly* combining with the iron of the nail. In both these cases, the combining oxygen is producing heat. It is easy to tell that a burning match gives off heat; it is difficult to measure the heat given off by a rusting nail, but it can be done. This sort of combination of oxygen with other kinds of matter is called *combustion*.

When you breathe air into your lungs, some of the air is taken into the blood and carried through the arteries to food materials stored in the muscles and other tissues. Here the oxygen combines with the food materials and produces heat to warm your body and energy to move your muscles. This combination of oxygen with the food materials is really slow combustion, just like the rusting of a nail. Since your heart must continue to beat as long as you are alive, you have a continuous need for energy; so you must continuously burn food materials in your tissues to keep your heart beating. When a human being is deprived of air for even a few minutes — as, for example, in drowning — his heart cannot get the oxygen it needs for energy, and the heart stops

heating. Thus, oxygen is not only the most abundant element, but it is also the most important to living beings.

Everyone has seen some form of the element carbon. A piece of coal, a burned match, the lead of a lead-pencil, a diamond, and soot from a burning candle — all these are forms of the element carbon. A diamond is the hardest natural material known. (Up until very recently, diamond was the hardest, but now chemists have made a compound of the elements carbon and boron that is harder than diamond.) A diamond is so hard because the carbon atoms that make up the diamond are packed very closely together.

Everyone knows that diamonds are valuable, and one that is entirely transparent, with no elements mixed into it in colour it, is very rare. The closely-packed atoms of a diamond have a remarkable effect on light that passes through the diamond. They cause the light to come out of the diamond in bright sparkles of all the colours of the rainbow. Because of this, we say that a diamond has *fire* and *lustre*, and these two qualities are what make diamonds so highly prized as jewels.

Some diamonds are black or dark brown. These diamonds are used in industry to cut, grind or drill hard metals, such as steel.

Until recently, all diamonds were mined from the earth. But in 1955, an American company began to manufacture diamonds. These diamonds are the black kind. The manufacturing process is a secret, but we can make a pretty



ROUGH DIAMONDS



CUT DIAMOND



THREE FORMS OF CARBON:
DIAMONDS
GRAPHITE
COAL

GRAPHITE



ANTHRACITE



LIGNITE



BITUMINOUS COAL



Charcoal is made out of wood.



During the "coal age," about 250 million years ago, huge tree-ferns and giant mosses flourished in the hot, humid weather. These plants toppled to the ground when they died and sank in the mud, forming the basis for coal deposits.

good guess at how it is done. In 1887, a French chemist named Henri Moissan dissolved some charcoal (a form of carbon) in molten iron. He plunged the iron into water. The cooling iron exerted tremendous pressure on the dissolved carbon, and the carbon formed tiny diamonds. The modern process, too, uses some kind of great pressure to squeeze the carbon atoms as close together as they are found in diamonds.

The lead in a lead pencil is not really made of the element lead — it is a form of carbon called *graphite*. (Once upon a time, lead pencils actually did have thin rods of lead in them.) The carbon atoms in graphite are connected together in the form of thin sheets. These sheets, layer upon layer, easily slide

What causes the "writing" when you write with a lead pencil?

over one another. This is why part of the graphite of a pencil so easily slides off to leave a line on the paper upon which we are writing. Powdered graphite is used instead of oil to help parts of machines to slide easily over one another.

In the third kind of carbon, represented by charcoal and carbon black, the atoms are arranged in tiny interlocking flakes. This is called *amorphous* carbon. Charcoal is made by burning wood in an insufficient supply of air. Carbon black is made by burning natural gas under like conditions. Burning in this manner gets rid of the other materials that make up wood and natural gas, and leaves behind nearly pure carbon.

How is charcoal made?

Carbon black has many uses. You are looking at one of them right now.

Carbon black mixed with the proper oils makes printer's ink. Also, the ink on black typewriter ribbons and the surface of black carbon paper contain carbon black. Carbon black is added to rubber to increase its toughness and wearing qualities. Every automobile tyre contains several pounds of carbon black.

Coal is almost all carbon. *Bituminous*,

Where did coal
come from? How
was it formed?

or soft, coal is
eighty-eight per-
cent carbon, while
anthracite, or

hard, coal is ninety-five percent carbon. You probably know that all coal is mined, but how did the coal happen to be in the ground? About 250 million years ago, the climate all over the world, except in the most northern parts, was warm and damp. It rained much, and it was always as warm as it

now is in tropical regions. Swamps covered much of the surface of the earth. Among the many plants that grew in abundance in the warm, wet climate were some called tree-ferns. They looked like huge ferns, some being a hundred feet tall. There were no trees in the world at this time. The tree-ferns were not made of wood, but of a softer material. However, like wood, this material was largely carbon. The trunks of tree-ferns were green and scaly, and at their tops grew fronds like those on fern plants today.

Tree-ferns grew in great numbers, making forests in all parts of the world. The forests were so thick and the tree-ferns grew so close together that no sunlight could ever shine through the fern tops to the ground beneath.

When the tree-ferns died, they fell into the swamps in which they were standing and sank into the mud. More

The pressure of layers of tree-ferns and mud as well as the earth's folding crust changed plants to coal beds.





Thousands of compounds from vanilla flavouring and medicine to perfume and explosives are made out of coal tar by chemists.

tree-ferns died and fell upon those that were already buried. More mud covered the newly-fallen plants. The weight of the fallen tree-ferns and the mud pressed heavily upon those that were buried deeply. Water and other liquids were pressed out of the tree-fern trunks. Later, tremendous pressure of the earth's folding crust further squeezed the remains of the buried plants. This process took tens of millions of years, and at its end, practically nothing was left of the buried tree-ferns but large masses of carbon. These masses are the coal beds that we mine for coal today.

Coal has been found in thirty-seven of the fifty United States. Last year, more than a half million tons were mined. Most of this coal was burned to provide heat for homes and power for factories. But about one-quarter of all the coal mined was used to make thousands of different kinds of plastics, dyes, varnishes and lacquers, perfumes, synthetic rubber, explosives and drugs. How was this done?

To obtain material from coal to make all the things we have just listed, the coal is placed into large ovens, called by-product ovens, from which all air is excluded. The coal is then heated red-hot. Ordinarily, at this heat, coal

burns, but the coal in by-product ovens cannot burn. Why not? Because, as we learned, burning is the rapid combination of oxygen with another material. Since air is excluded from the by-product ovens, there is no oxygen to combine with the coal. Instead of burning, the heated coal separates into the materials from which it is made. Chief among these are coal gas, tar, coke and a compound called ammonium sulphate. The coal gas may be piped away from the by-product ovens and sold to consumers for heating their homes or cooking their food. The ammonium sulphate is used to make fertilizer. The coke is used by iron and steel mills in the process of smelting.

The materials in coal tar are a chemist's delight. By separating coal tar into its principal compounds — benzene, toluene, phenol, anthracene and naphthalene — the chemist can make thousands of compounds ranging from vanilla flavouring and medicine to perfume and TNT.

There can be no argument about the fact that if it had not been for iron, we would never have been able to

build the great industries that have made modern civilization possible. Iron's strength, hardness and springy



The Bessemer process for converting pig iron into steel takes about fifteen minutes.

Metal is separated from ore in blast furnaces.



toughness have made possible the construction of skyscraper frames, ocean liners, battleships, railways, automobiles, typewriters, tanks and most of the machines and machine tools that have given us our industrial civilization.

In 4000 B.C., Egyptian pharaohs valued iron more highly than gold. At that time, the only iron available came from rare pieces that fell to earth as meteorites. It was not until 1500 B.C. that anyone learned to produce iron in fairly large quantities. At this time, a people of Asia Minor, the Hittites, learned how to obtain iron from iron ore. They used the iron to make swords, spears, helmets and shields. With these weapons they were very successful in war, because their enemies had bronze weapons that were softer than iron. Almost a thousand years more passed before most of the peoples who lived on the shore of the Mediterranean Sea had learned to obtain and use iron. When Julius Caesar landed in Britain, in 55 B.C., he found the people making iron.

Iron is the fourth most abundant element in the earth's crust, where it makes up one-twentieth of the total of all elements. However, if many scientists are correct in their belief that the earth's core (about 4,300 miles in diameter) is largely iron, then iron, and not oxygen, is the earth's most abundant element.

In the earth's crust, iron is in the form of iron ore. This ore consists of iron combined with oxygen. In order to get the iron in a form we can use, we must

**How do we put
iron in a form
so that it can
be used by man?**

separate it from the oxygen. The process of doing this is called *smelting*. In general, smelting is done by heating iron ore mixed with charcoal or coke. Charcoal and coke both are forms of the chemical element, carbon. When iron ore and carbon are very hot, the atoms of oxygen become disconnected from the iron and connect with the carbon. This leaves iron in the form of the metal that is so familiar to us. What makes this process so easily workable is due to the fact that when the oxygen combines with the carbon, the compound that is formed is a gas that is driven off by the heat into the atmosphere. Thus, we do not have to worry about separating the carbon-and-oxygen compound from the iron we have obtained.

In the iron industry, smelting is done in huge ovens called *blast furnaces*. These furnaces are tall steel cylinders lined with brick, ten or twelve storeys high. A fire is built in the bottom of the blast furnace, and iron ore and coke are dumped into the top of the furnace. At the bottom, encircling the furnace, is a ring of pipes. Through these pipes a strong blast of air is continually blown into the furnace in order to make the fire inside very hot. It is this blast of air that gives the blast furnace its name. In iron smelting plants, eight or ten blast furnaces are built next to each other in a double row. During the day, great columns of smoke pour out of the tops of the furnaces, while at night their fires light up the sky with a red glow.

The smelted iron collects at the bottom of the furnace. The iron is molten and runs as easily as water. When enough iron has collected, a hole is



opened on the side at the bottom of the furnace. From this hole, the molten iron flows out of the furnace in a fiery stream. The iron flows into moulds lined with sand. When the iron has cooled, it is in the shape of long heavy bars called "pigs," and the iron is thus called "pig iron." Most blast furnaces produce 400 to 500 tons of iron a day, and some can produce as much as 1,000 tons.

Pig iron is hard and strong, but it is brittle, which means that it is easily broken by a blow. If our machines were made of pig iron, we would continually have to be repairing their broken parts. What we need is a kind of iron that is tough as well as hard. The two main kinds of tough iron are called *wrought iron* and *steel*.

If we add just the right amount of carbon to iron, we get steel. This kind of iron is not only tough, but it can be made very hard. Steel is easily shaped by casting, rolling, drawing and hammering. It has great resistance to breaking under pull. An excellent grade of steel was manufactured at Damascus and at Toledo in Spain during the Middle Ages. Swords manufactured in these two cities were highly prized for the

**How is
steel
made?**

springiness and hardness of the steel. The point of one of these swords could be bent all the way around to the hilt without breaking the blade. Armour, too, was made of steel.

One process for making steel uses a furnace called a *Bessemer converter*. It converts iron to steel, and was invented by Henry Bessemer. This furnace is a pear-shaped vessel, twelve to fifteen feet high, constructed of iron plates and lined with brick. It is hung by two thick, hollow iron rods attached to its sides at half its height, so that it can be tipped on its side. The brick lining is heated white-hot by a coal or oil fire. The converter is turned on its side and ten to twenty-five tons of molten pig iron are poured into it. It is brought back to an upright position and 20,000 cubic feet of air per minute are forced through one of the hollow supporting rods. The air enters the converter through the bottom and rushes upward through the molten iron. This burns out the impurities in the iron. The action is spectacular as a great torch of flame shoots out of the mouth of the converter with a roar and a shower of sparks. Within ten to twenty minutes the flame dies out. The converter is again turned on its side and a mixture



A chemist is shown analyzing a piece of steel to determine its carbon and iron content.



of the elements manganese and carbon is put into the converter. This mixture, called *spiegeleisen*, changes the iron to steel. A modern converter can produce one hundred tons of steel in an hour.

A modern steel and iron plant employs many chemists to analyze samples of steel and iron taken from the furnaces. In this way the steel and iron can be made to have the proper purity and other needed qualities.



Organic Chemistry

In the year 1828, a young German chemist, Friedrich Wöhler, made in his laboratory a compound called *urea*. The news of this accomplishment astounded the scientific world. Urea had been known as a compound made by human kidneys and as one of the waste products of the body. What, then, was so remarkable about Wöhler's making urea in a labo-

What is organic chemistry and carbon chemistry?

rich Wöhler, made in his laboratory a com-

The German chemist Friedrich Wöhler, in 1828, accidentally made the organic compound urea in his laboratory. Wöhler's experiment destroyed the belief that compounds usually found in living things could not be made from non-living materials.



ratory? Before Wöhler's accomplishment, it had been believed that any of the materials of a living thing — plant or animal — or any of the products of these living things, contained an ingredient called a "vital spirit." This vital spirit was believed to be forever beyond man's grasp, and without it he could never reproduce any of the materials of which living things are made. By making urea in a laboratory, Wöhler had, at one stroke, destroyed the vital spirit theory.

As soon as the meaning of Wöhler's success was understood, scientists realized that the whole great field of the chemistry of living things had been opened. This new field of chemistry soon had two names: *organic chemistry* and *carbon chemistry*.

Since this field of chemistry had to do with the chemistry of living things — that is, living *organisms* — it is not hard to see where the name "organic chemistry" came from.

As knowledge of the field of organic chemistry grew, it was found that almost all of the tens of thousands of compounds found in living organisms not only contained carbon, but also depended on the properties of carbon. So the new field was also called *carbon chemistry*.

Since Wöhler's discovery, organic chemists have studied more than 700,000 carbon com-

pounds. It is now clear that carbon can form more compounds than any other element. Why? Because carbon



Carbon compounds: rubber, cotton, wood, sugar, wool.

atoms can connect to each other in long chains and in rings. Most molecules have only a few atoms, but carbon atom chains may contain hundreds of atoms. Usually, organic compounds contain hundreds of atoms. Carbon can combine with most other elements. There are more carbon compounds than all other chemical compounds put together. Wood, paper, wool, nylon, rubber, oil, alcohol, soap, fat and plastics are carbon compounds or mixtures of carbon compounds. Many compounds, called *hydrocarbons*, are composed only of carbon and hydrogen. Among them are natural gas, fuel oil, petrol and paraffin. Other compounds, made up of carbon, hydrogen and oxygen, are called *carbohydrates*.

In working with these compounds, the organic chemist takes apart linkings of carbon chains and puts them together in different combinations. To understand what the organic chemist is

doing, you might picture a carbon atom as a tiny ball with four sharp hooks projecting from it at opposite points. These hooks can link up with the hooks on other carbon atoms or the atoms of other elements — hydrogen, for example. To understand just how carbon atoms are linked to each other or to other atoms requires many years of study by the organic chemist. Today, most chemists are organic chemists.

We learned that one way in which carbon atoms can link up is in rings. In the early days of organic chemistry, it was found that a large number of hydrocarbons had six carbon atoms joined in a ring. Organic chemists soon found they had a difficult problem when

Kekulé's dream solved the carbon ring linkage riddle.



A carbon atom acts just as if it had four hooks.



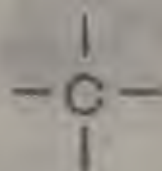
You have heard of octane in petrol. Here is the formula for octane, which shows how carbon atoms may be linked in chains.

they tried to figure out just how the carbon atoms formed the ring. Two of the connecting "hooks" on each carbon atom were used in joining it to the carbon atoms on each side of it. One more "hook" on each carbon atom was used to join some other atom to the ring, perhaps a hydrogen atom. But what was done with the other "hook"? If chemists considered it to be connected in a double connection to neighbouring carbon atoms, they ended up with too many connections. They could not just consider it to be waving around empty, because all the "hooks" on an atom in a compound must be connected.

One afternoon, a German chemist, Friedrich Kekulé, who was working on the problem of the carbon ring linkage,

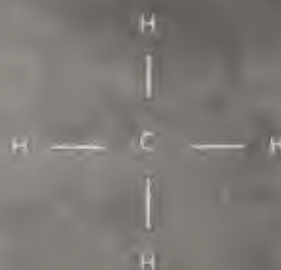


These atoms 'hook' four other atoms to form the compound, methane.

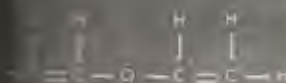


Since a carbon atom doesn't really have hooks, a chemist shows that a carbon atom can combine with four other atoms in the way shown here.

A chemist writes the formula for methane gas in this way.



They can hook onto other atoms, as shown by the chemical formula for ether.



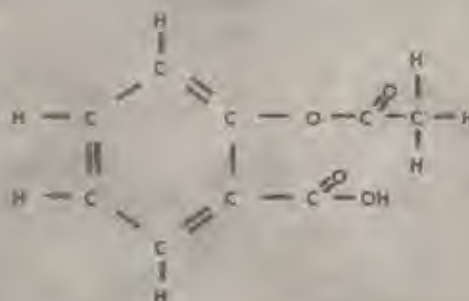
Carbon atoms can link together in rings, too. This is the arrangement that Kekulé dreamed. It is the formula for benzene, a liquid that is used to dissolve varnishes and shellacs.

dozed off in a chair before the fireplace. Kekulé dreamed that he saw the six carbon atoms dancing around among the flames in his fireplace. Suddenly, the dancing atoms formed a ring with every "hook" used in just the right way. Kekulé remembered his dream when he awoke, and the problem of the six-atom ring was solved. The arrangement Kekulé dreamed is shown on this page.

There is an old saying that all flesh is grass. This means that all animals get their flesh either by eating plants or by eating other animals that eat plants. Cows and sheep eat grass. In their bodies, the grass eventually becomes flesh. Cougars do not eat grass,

What do plants provide us with?

grass. This means that all animals get their flesh either by



Here you can see carbon combining in many ways. The chemical formula shown above is for aspirin.

but they do eat cows and sheep. In the body of the cougar, the cow and sheep flesh becomes cougar flesh. Thus, indirectly, cougar flesh comes from grass. Aphids eat the juices of rosebushes. Praying mantises eat aphids. Robins eat praying mantises. Hawks eat rob-



"FLESH IS GRASS"

CAT EATS BIRD,
THAT FEEDS ON INSECTS,
WHICH LIVE ON PLANTS.

bins. Thus, hawk flesh was once rosebush juice. Human beings maintain the flesh on their bodies by eating both animal flesh and plants. In short, then, every animal is dependent on plants for food.



Leaves "inhale" carbon dioxide and "exhale" oxygen through small holes called stomata, shown above in a highly magnified cross section of a leaf. All green plants manufacture their own food in a process which scientists call photosynthesis.



Most plants — the green plants —
 Where do plants manufacture their
 get their food? own food in a won-
 derful chemical

factory. The green plant uses two raw materials: water from the soil and carbon dioxide gas from the air. To do the work of changing these two raw materials into food, the green plant needs energy — just as any chemical factory needs energy. The plant gets the needed energy from sunlight.

What kind of food does a green plant make from carbon dioxide and water? It makes a kind of sugar called *glucose*. If you were to eat some glucose you would find that it does not taste as sweet as the sugar you put on your cereal.

Right after a plant makes glucose in its leaves, the plant changes the glucose to starch. The starch, which is dissolved in water, is carried by the plant through tiny tubes in its stem to the root where the starch is stored.

In addition to making starch, a green plant makes *cellulose*, the main constituent of wood. Why is it that only green plants can make glucose, starch and cellulose? Because only green plants contain a carbon compound called *chlorophyll*. In fact, it is the green color of chlorophyll that makes plants green. The process in which a green plant uses water, carbon dioxide and chlorophyll to make glucose in the presence of sunlight is called *photosynthesis*. This word means "put together with the help of light."



Pin a strip of tinfoil or black cloth across the upper surface of some leaves of a house plant. A geranium is a good plant to use. Have each strip cover about a third of the leaf. Place the plant in a sunny window for two or three days. Cut the partly-covered leaves from the plant. Remove the tinfoil or cloth. Soak the leaves overnight in alcohol. The next day, take the leaves out of the alcohol. With a medicine dropper, drop iodine on both parts of the leaves that were covered and the parts that were not. The parts that were not covered will turn purple or dark blue. This colour proves that starch is present.



Chlorophyll plays a very interesting role in the process of photosynthesis. In a green plant, six molecules of carbon dioxide

Chlorophyll:
What does
it do?

combine with six molecules of water and 673,000 calories of energy from sunlight to make one molecule of glucose and six molecules of oxygen. If the chlorophyll is not present, the sunlight will not cause the water and carbon dioxide to combine. Yet the chlorophyll does not become part of the glucose. Evidently, then, the chlorophyll helps the water and carbon dioxide become glucose, but the chlorophyll itself remains unchanged. Chemists know about many compounds that act this way. Such compounds are called *catalysts*. This term comes from the Greek words which mean "entirely loose" and

refers to the fact that the catalyst is entirely loose from the compounds it helps to combine.

The chemical factory within a plant does not end its work with the making of glucose, starch and cellulose. The water that enters the plant through the roots brings with it many dissolved chemical compounds called *minerals*. The plant combines these minerals with starch to make fats, oils and proteins. You have probably noticed how oily peanuts are. Lima beans and kidney beans contain much protein. And nuts contain fat.

Did you ever stop to wonder why, during all the millions of years that animals have been living on earth, all the oxygen

What is the
oxygen-carbon
dioxide cycle?

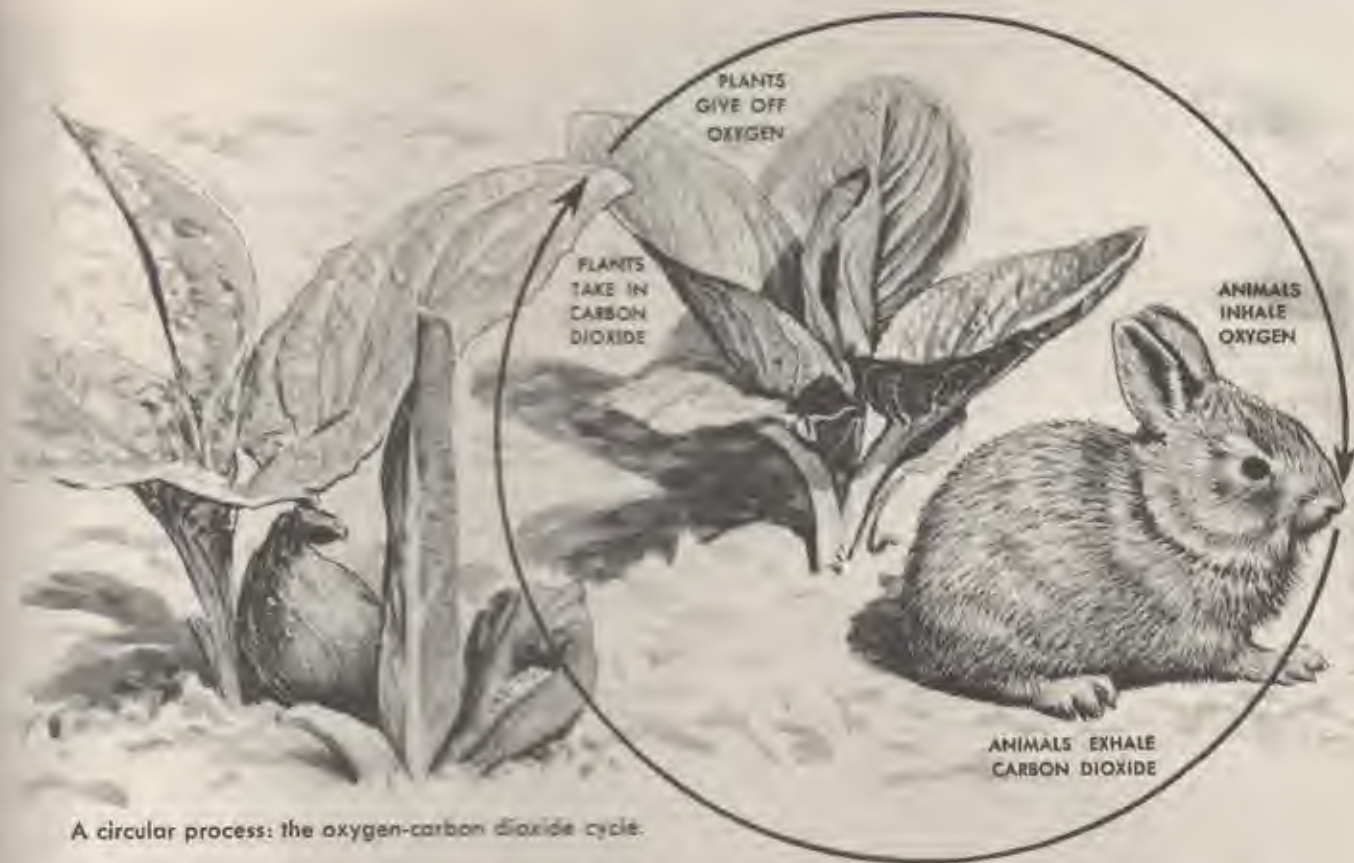
in the air was not long ago all breathed up? We just learned the answer to this question when we learned that the process of photosynthesis not only results in the manufacture of glucose, but also oxygen. So, it is the activity of plants that continually renews the oxygen in the air. But this is not the end of this wonderful arrangement. We learned that we slowly burn food materials in our tissues. These stored food materials are carbon compounds. When oxygen combines with these compounds, water and carbon dioxide gas are formed. When we exhale a breath from our lungs, it is made up partly of water and carbon dioxide. By breathing out carbon dioxide into the air, we make this gas available to plants for the process of photosynthesis.

Here we have a remarkable circular

HOW CAN YOU USE A CATALYST?



Place a lump of sugar in a saucer. Try to light it with a match. Can you make the sugar catch fire? No. Now rub the lump of sugar in an ashtray, so that the sugar picks up some cigarette or cigar ashes. Place a lighted match against the sugar where it is smeared with ash. Does it catch fire now? Answer: Yes. Did the ash act as a catalyst? Answer: Yes.



A circular process: the oxygen-carbon dioxide cycle.

arrangement: animals use oxygen and make carbon dioxide, while plants use that carbon dioxide and make oxygen for animals to use. The circular process is called the *oxygen-carbon dioxide cycle*. A cycle is a process that repeats itself over and over again.

After two or three days of sunlight, you will see gas in the upper part of the test tube. You may also see gas bubbles sticking to the upper surfaces of the leaves of the plant. This gas is oxygen.

From a pond or stream get a plant that

**How can you
show that plants
manufacture oxygen?**

lives under
water. The
plants that are
put into aqua-

riums can also be used. Put the plant into a large jar or an aquarium full of water. Place the jar in a sunny window. Place a large glass funnel upside down over the plant. Fill a test tube with water. Keep your finger over the end of the test tube so that you do not lose any water from it, and then place the test tube upside down over the part of the funnel that is uppermost in the jar.



This experiment proves that plants give off oxygen.



Most chemists specialize in not more than one or two fields. Thousands are employed in the pharmaceutical industry, developing new drugs and cosmetics for a world market.



The agricultural chemist plays an important role in the development of new fertilizers and insecticides. Shown here is an airplane "dusting" cultivated land with insecticide.



The Branches of Chemistry

Chemistry is divided into several branches. Let us now explore some of them.

Man has been using chemistry in farming for a long time without knowing it. As far back as the Middle Ages, farmers used to leave one field out of three idle each year. They did not know the scientific reason why this was a good idea,

What is agricultural and food chemistry?

but they did know that after a field had lain idle for a year, it grew better crops. Modern *agricultural chemists* know that growing plants remove certain compounds from the soil. During the year that a field is left idle, the soil gets back from the air and from ground water the compounds that the plants removed. The next year, plants will then be able to obtain from this field the compounds they need. Thanks to agricultural chemists, we know what com-



Many chemists specialize in work connected with atomic energy.

Chemical research goes on in the petroleum industry to improve fuel and make new products.



pounds plants need, and we put these compounds in the soil in the form of fertilizers. We no longer need to leave a field idle for a year.

Insects destroy millions of tons of food crops each year. This is a serious loss, but the amount of food insects would destroy if man did not fight them would be disastrous, probably causing starvation. It is the agricultural chemists who discover the sprays farmers must use to kill insects.

Once upon a time, well-fed cows in one part of the country were thin and sickly, while well-fed cows in other

parts were fat and healthy. *Food chemists* learned that the healthy cows were fed corn that had the husks on the corn ears, but the sickly cows were fed wheat that had lost the wheat leaves during threshing. The husks are the leaves of the corn, and they have certain compounds cows need for health. When the sickly cows were fed green leaves, they too became healthy.

Food chemists are working on the possibility of making food for man from seaweed. As the population of the world increases, we soon may turn to the seas for other kinds of food besides fish.

We learned what organic chemistry is — the chemistry of carbon compounds. *Inorganic chemistry* includes the chemistry of all the other elements. One interesting group of compounds that modern inorganic chemists are working on is called *silicones*. The main element in these compounds is *silicon*, the second most abundant element in the earth's crust. Silicon, like carbon, can make compounds in the form of long chains. There are silicones that are rubbery and which won't crack in sub-zero weather. Other silicones are lubricants that will run in sub-zero weather. From these silicones are made gaskets, shock absorbers and other parts of machines that are used in polar regions. Do you have a coat that is "rainproof"? It is treated with a silicone that sheds water.

Transistors are electronic devices that make possible portable radios and giant computers. Transistors are made of the elements zirconium, germanium or selenium. Before inorganic chemists purified these elements, making efficient transistors was not possible.

We have learned that the slow burning of food materials in the tissues of the human body is a kind of chemical change. This is not the only

chemical change that goes on in the body. On the contrary, in every part of the body chemical changes are constantly taking place. One group of chemists, the *biochemists*, have studied the chemistry of the body. They have found so many hundreds of complicated chemical changes in the human body that they are still at the beginning of their study. However, they already have knowledge gained from thousands of experiments, and this knowledge is enough to have revealed many wonderful things about the body.

Biochemists have learned how the chemicals of the blood react with the oxygen of the air to form the scab that stops you from bleeding to death from even a little cut.

Biochemists have learned that the digestion of food, the changing of digested food into body tissue, the use of stored food and the getting rid of waste products are all activities of the body that involve chemical changes.

Medical chemistry is really a branch of biochemistry, but medical chemistry concerns itself with the diseases of the body. Did you ever hear of anyone being told by his doctor to take a laboratory test of his blood or urine? The blood is the transportation division of the body. Chemi-

**What is
inorganic
chemistry?**

**What is
biochemistry?**

**What is
medical
chemistry?**

CHEMISTRY AS A HOBBY

CHEMISTRY IN COOKING

CHEMISTRY IN RESEARCH



cal compounds dissolved in the blood are constantly being carried from one part of the body to another. The urine carries some of the body's waste compounds. Medical chemists have learned pretty well what compounds should be carried in the blood and urine of a healthy person. If medical chemists make tests on the blood and urine and find too much or too little of certain compounds, or if they find new compounds in these two body liquids, they can tell a doctor which of the organs of the body are not working properly.

In our bodies are certain organs called *glands*. These glands make chemical compounds that are put into the body's blood stream. For instance, one of these glands is the *adrenal gland*. It makes a compound called *adrenalin*. This compound makes our hearts beat faster when we are frightened or angry or excited. If you were to inject some adrenalin into a rabbit, you could make the rabbit so ferocious that it would attack and fight a dog. Medical biochemists discovered adrenalin and the compounds made by our glands.

Every day, doctors lean heavily on the work of medical chemists. In many cases, diagnoses which were almost impossible a few years ago are now quick and sure, thanks to the knowledge of the chemical processes of the body

painstakingly gathered by medical chemists.

Although chemistry had its beginning thousands of years ago in the work of the first alchemists, chemistry is really

Is there still
a need for new
chemists today?

a young science. Consider simply the fact that organic chemists have discovered more than 300,000 carbon compounds. Does this mean that most carbon compounds have been discovered and that it is becoming harder and harder to discover a new compound? No, it is quite the contrary. Since "discovering" new chemical compounds actually means making them by combining already-known compounds in new ways, the more compounds that are discovered, the more material there is to work with to make new compounds. It is for this reason that almost every day some new chemical discovery is announced. It may be a new man-made fibre with properties that neither cotton, wool, flax nor silk can match. It may be a new drug that will cure one of the diseases that are now considered to be incurable.

In agriculture there is a continuing need for chemists to find new ways of fighting the diseases and insects that destroy so much of our food crops. As

There is still a great need in our modern era for chemists in Government work, in private industry and in schools. Whether you enjoy chemistry as a professional pursuit or as a hobby, it is a fascinating subject to follow.



Less than 200 years ago, Henry Cavendish isolated hydrogen by pouring acids over metals. He called the resulting gas "inflammable gas." Now, scientists have developed the most powerful explosive force known, the H-bomb. But it is within man's power to use the progress in chemistry to destroy life, or to enrich it.



planetary space. If it had not been for chemists who developed powerful rocket fuels, the first artificial satellite could not have been launched. Still more powerful rocket fuels are needed, and so are new compounds that will help rockets to resist better the great heat caused by their re-entry into the earth's atmosphere.

There is, too, a great need for teachers of chemistry — in technical schools and colleges — who are not only able to teach their students how to combine atoms and molecules into new compounds according to the laws of chemistry, but who are also able to inspire their students to use science for the good of mankind. Endless opportunities await the chemist to help make the world a more comfortable and more humane place in which to live. This is the noble purpose of chemistry.

the population of the world increases so rapidly, chemists are wondering whether it might not be possible for man to make and use chlorophyll to produce food directly from the very abundant raw materials, water and carbon dioxide. This would do away with the need to grow crops, only part of which are used for food.

Man has just begun to explore inter-

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